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**Controls Design with Crossfeeds for Hovering Rotorcraft
Using Quantitative Feedback Theory**

by

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ABSTRACT

This work is extending the research accomplished on project NCC 2-751. A newly implemented helicopter model has been used to simulate 25 flight configurations near hover for the UH-60 RASCAL aircraft. A new engine model has been installed in the FORECAST simulation (alias UMGENHEL) for the better prediction of the yaw and heave responses.

Flight configurations #8 and #17 could not be made to trim to equilibrium in the FORECAST program and were removed from this crossfeed study. By applying the decoupling metric from project NCC 751 it was determined that the aileron to pitch and the elevator to yaw responses do not indicate the need for crossfeeds since both of them have a decoupling metric value over 20 dB (less than 10% coupling). In the case of the aileron to heave and the elevator to heave responses, the large size and the overlapping of the templates indicate that a low-order dynamic crossfeed cannot be found. The low-order dynamic crossfeed selection is proceeding, however, for the remaining eight crossfeeds. These crossfeeds and their associated decoupling metrics are shown in Figure 1. Note that most of them have successfully decoupled the system by 20 dB or more, except for the rudder to heave crossfeed (18.2 dB). It is probable that the engine model needs more accuracy to further improve the heave to yaw crossfeed decoupling metric value.

To see how the new low-order dynamic crossfeeds perform, a simulation was accomplished using MATLAB SIMULINK as shown in Figure 2. Flight configurations #1, #8, and #23 were loaded to test the crossfeeds. In Figure 3 the response to a lateral step input is shown. The 60-second time plot is intended only to show the trend. For actual flight control only the first few seconds is important to the pilot. Note from Figure 3 that all responses from the lateral step input remain heavily coupled. The large aileron to heave coupling (5 dB decoupling) is caused by the lack of an effective low-order dynamic crossfeed.

The aileron to yaw response appears heavily coupled for the configurations in Figure 3 even though the decoupling metric was a respectable 45 dB. The reason for this is that the decoupling effectively occurs only in the higher frequency ranges (3-10 rad/sec) and not in the lower frequency ranges (see Figure 3.3a). In the aileron to pitch response, the performance metric exceeds 20 dB, but the off-axis response is significant in the frequency range of 1-3 rad/sec. The inclusion of a dynamic low-order crossfeed for aileron to pitch should increase the decoupling.

In Figure 4, the longitudinal step input for hover shows heavy coupling in the elevator to heave response. The reason for this is the lack of an effective low-order dynamic crossfeed. In Figure 5 the effects of an inaccurate engine model can once again be seen in the large collective to yaw response. In Figure 6 the rudder step input for hover shows successful decoupling in the yaw axis for rudder to heave, rudder to pitch, and rudder to roll responses.

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Figure 1 PERFORMANCE METRICS

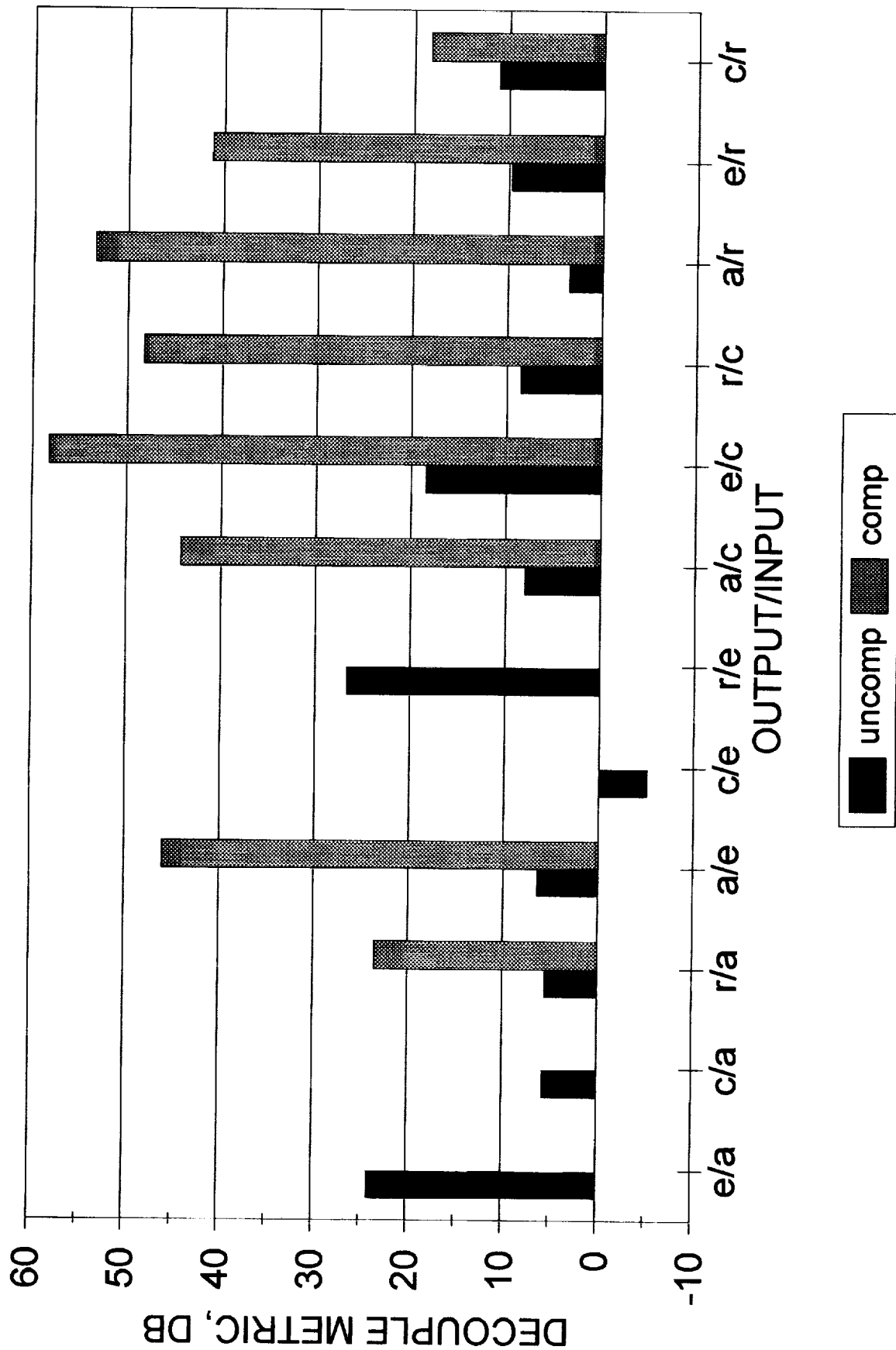


Figure 2

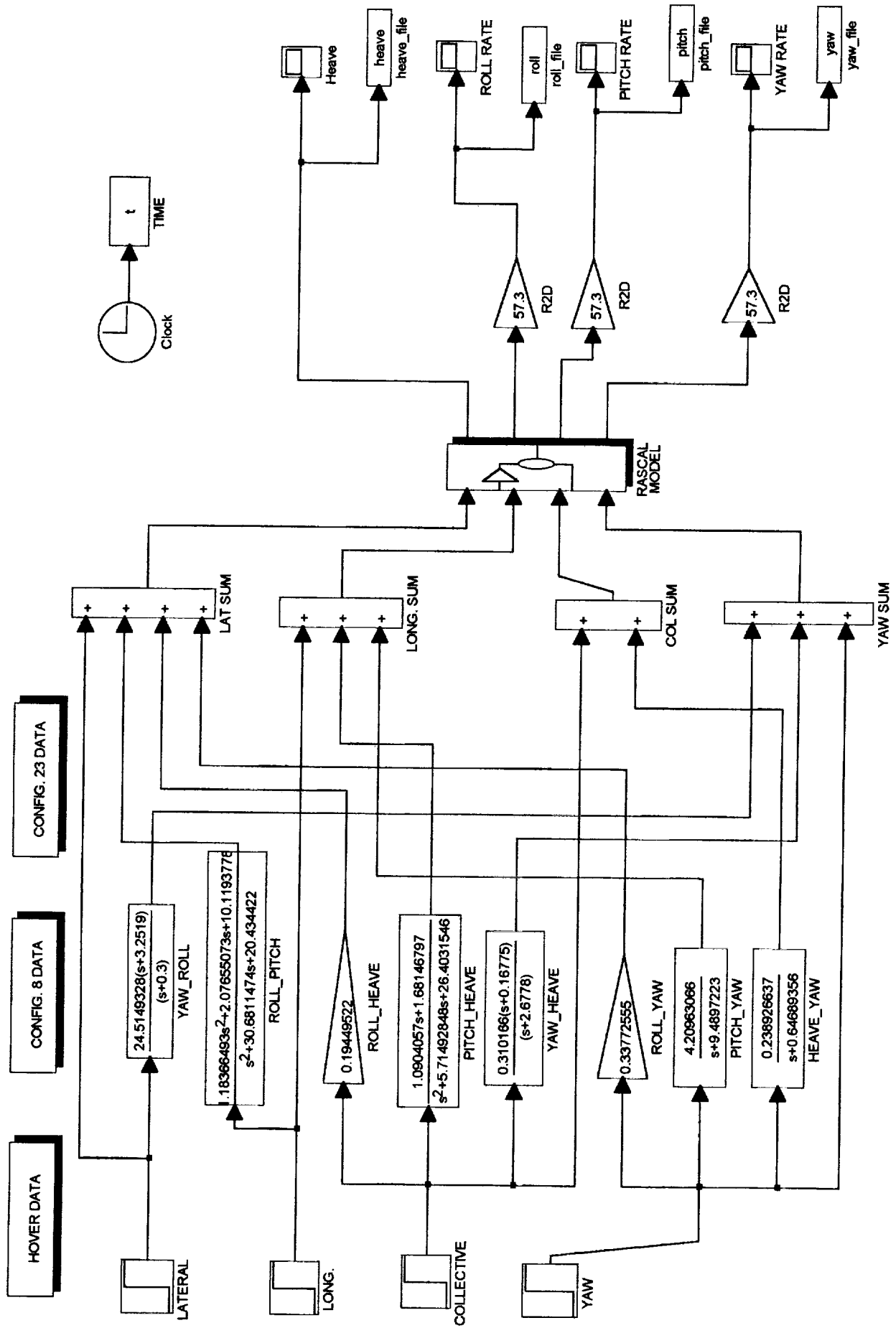


Figure 3 HOVER CONFIGURATION, LATERAL STEP INPUT

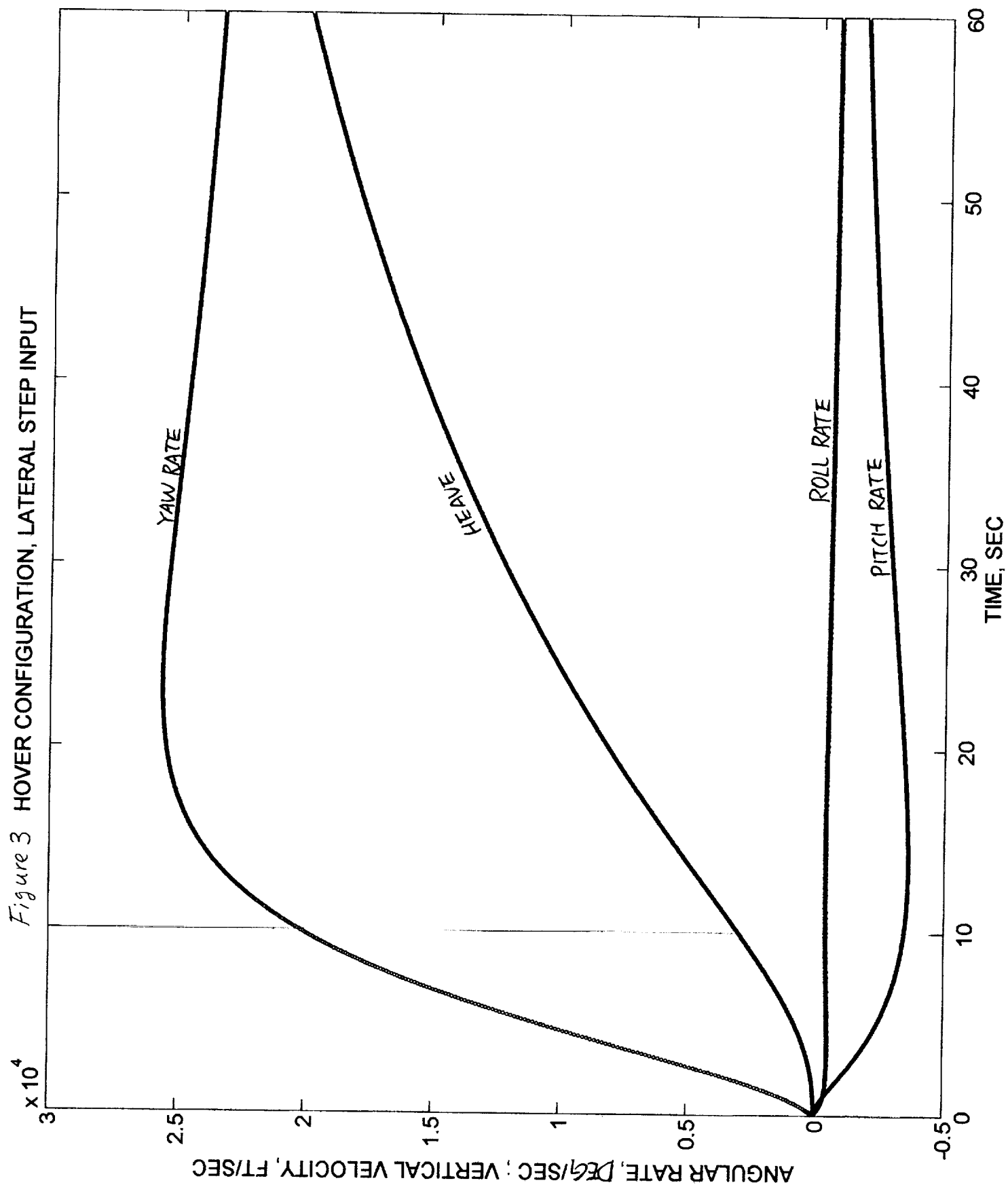


Figure 3.1a **FREQUENCY PLOT**
PITCH / ROLL

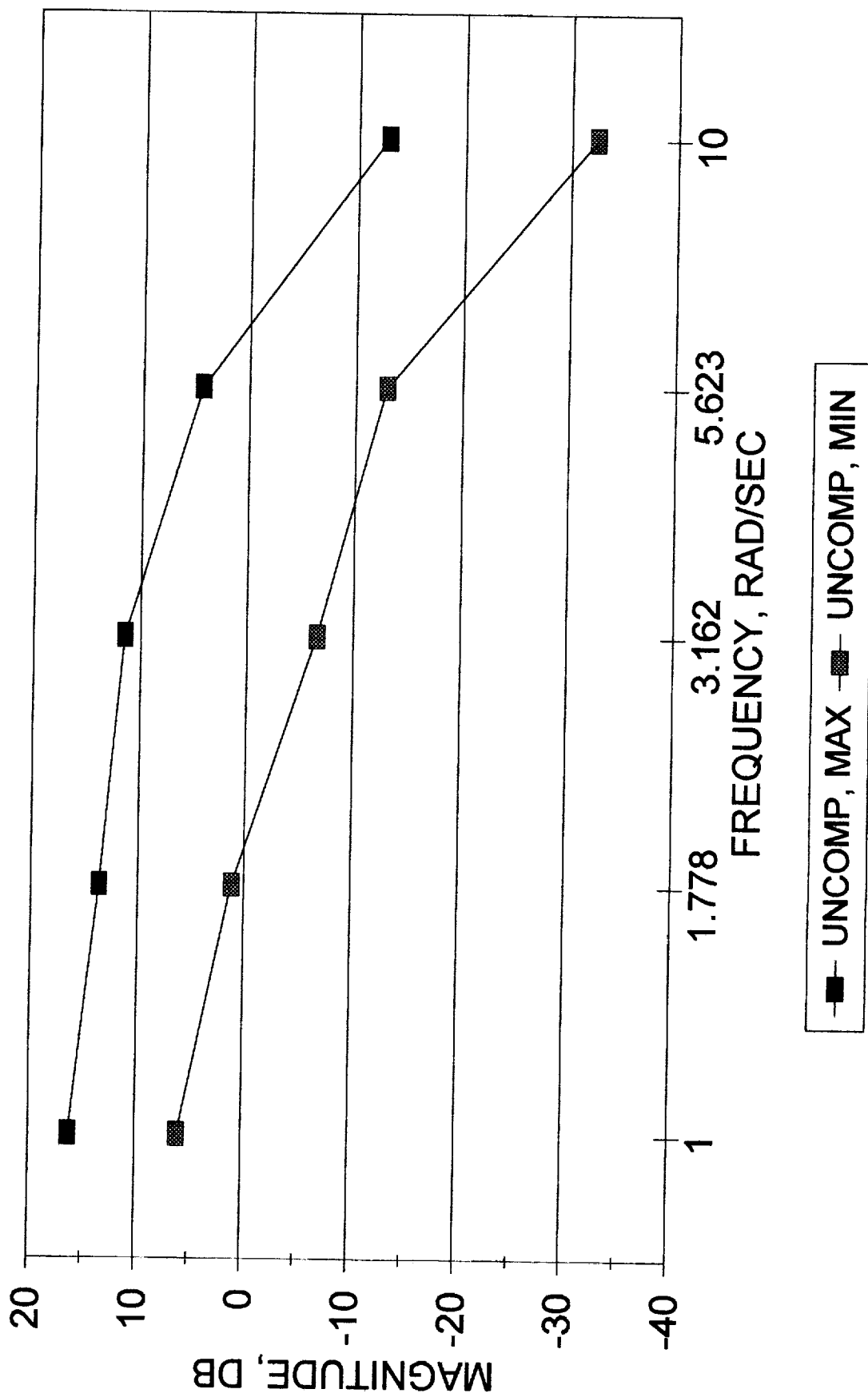


Figure 3.16 **SCATTER PLOT**
PITCH / ROLL

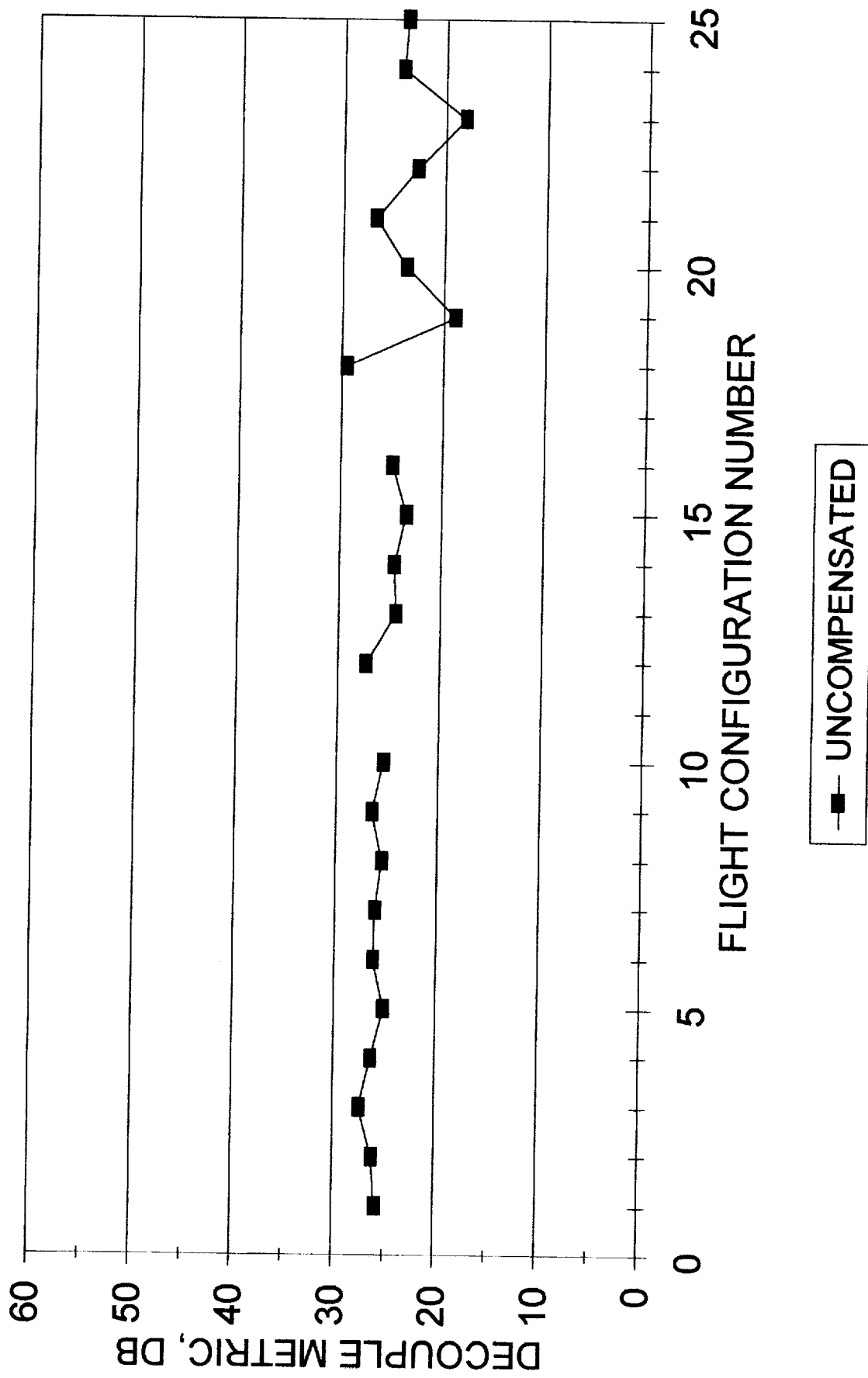


Figure 3.2 SCATTER PLOT
HEAVE / ROLL

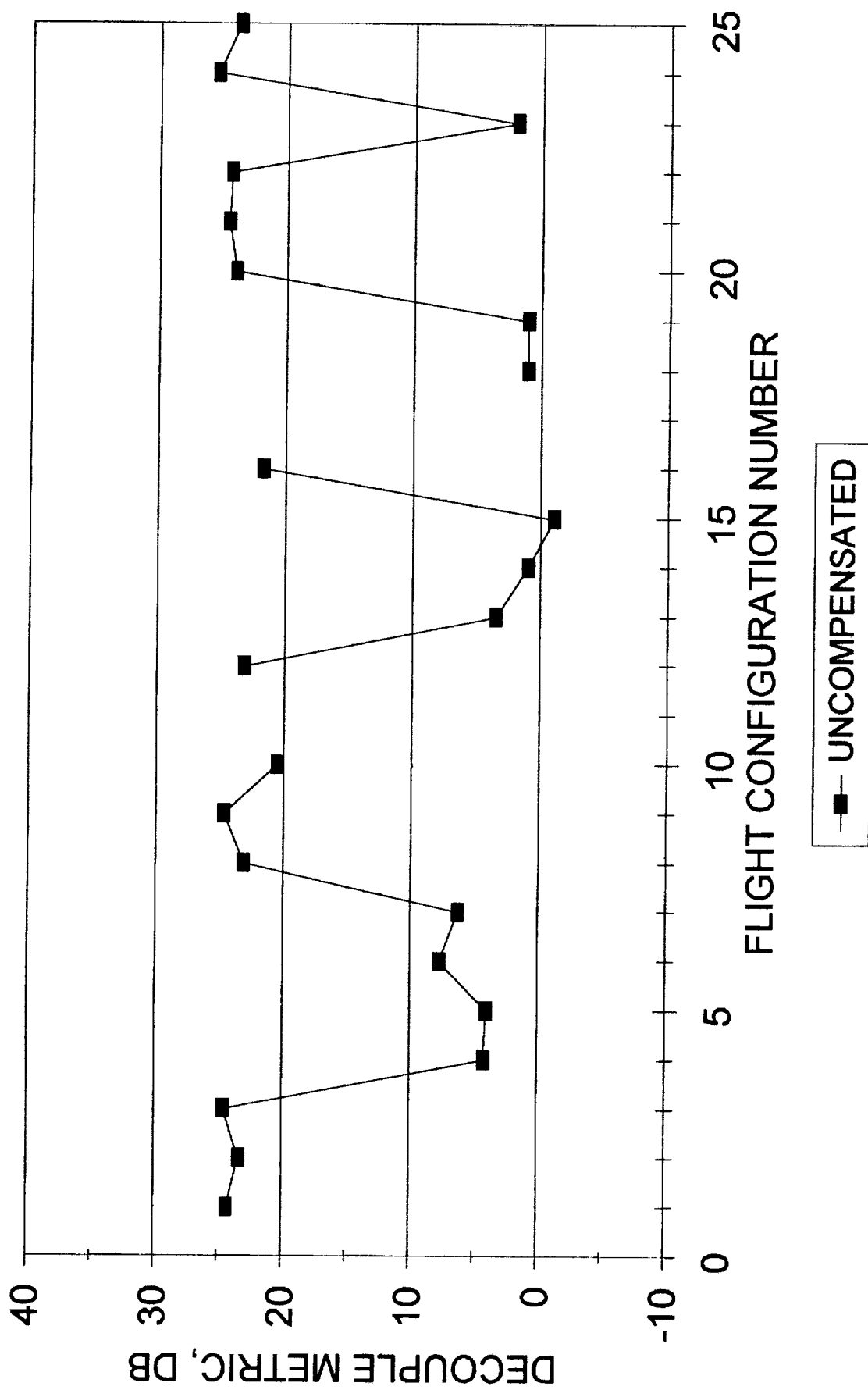
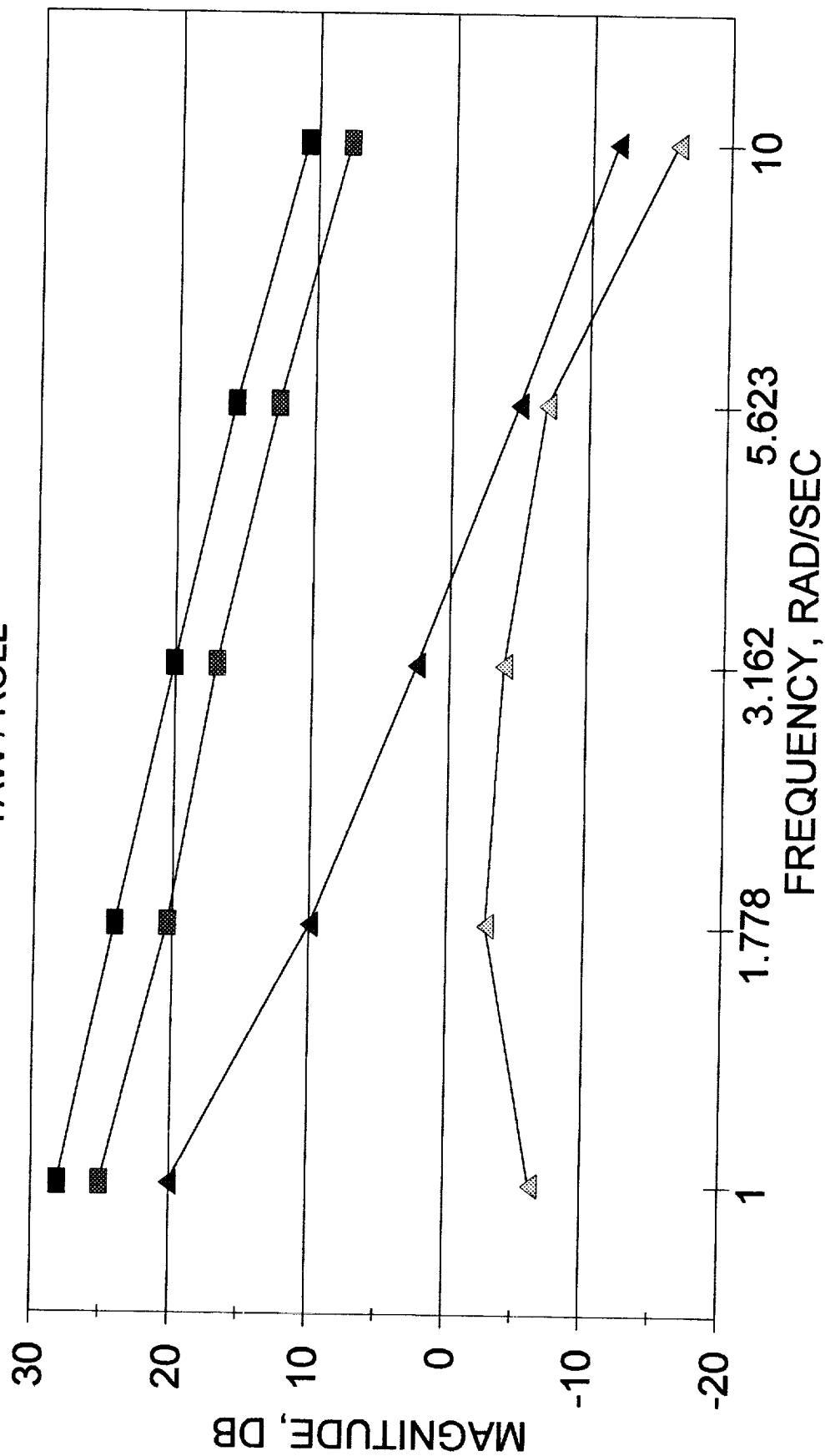


Figure 3.3a **FREQUENCY PLOT**
YAW / ROLL



UNCOMP, MAX
 UNCOMP, MIN
 COMP, MAX
 COMP, MIN

Figure 3.3_b **SCATTER PLOT**
YAW / ROLL

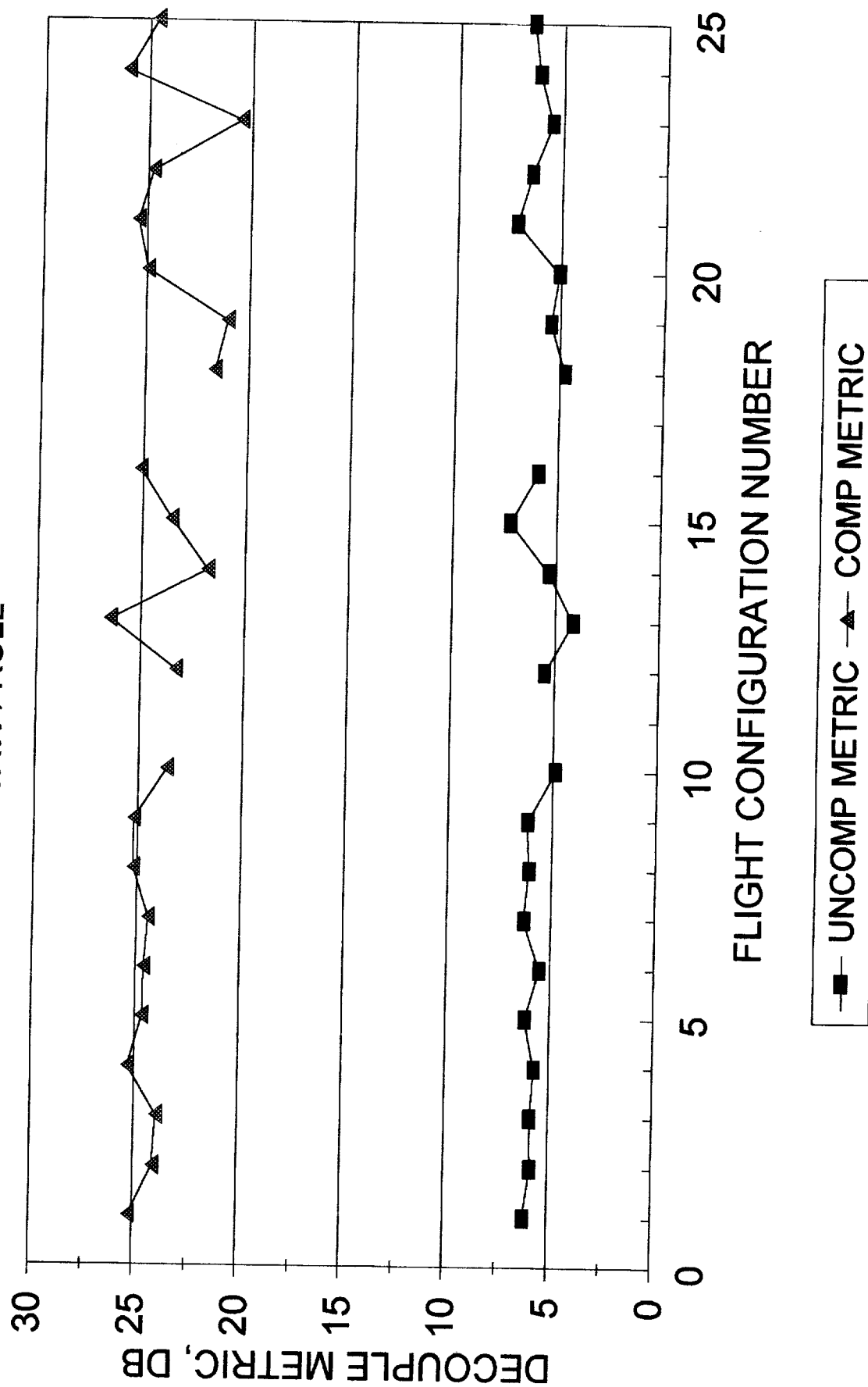


Figure 4 HOVER CONFIGURATION, LONGITUDINAL UNIT STEP INPUT

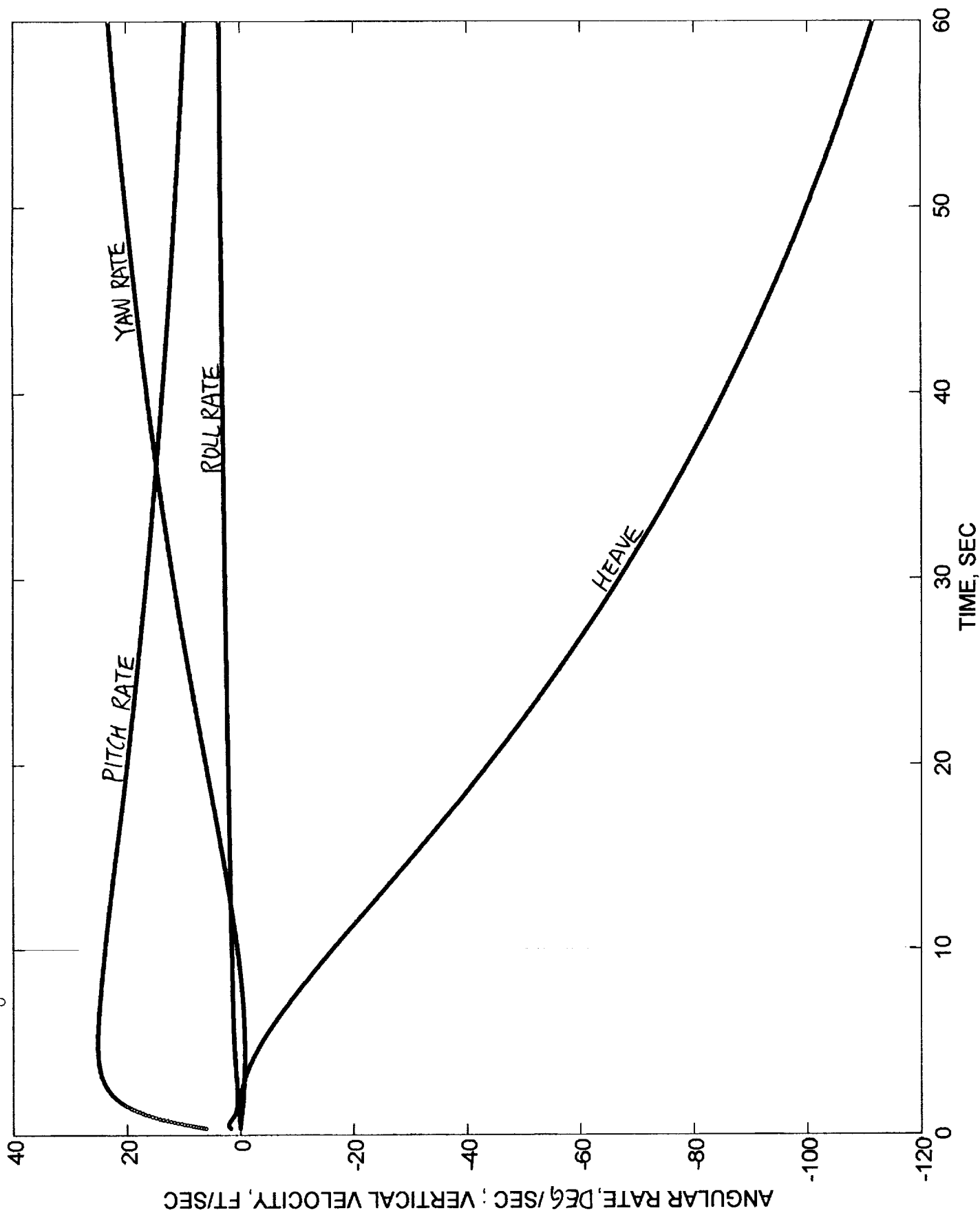


Figure 4/a **FREQUENCY PLOT**
ROLL / PITCH

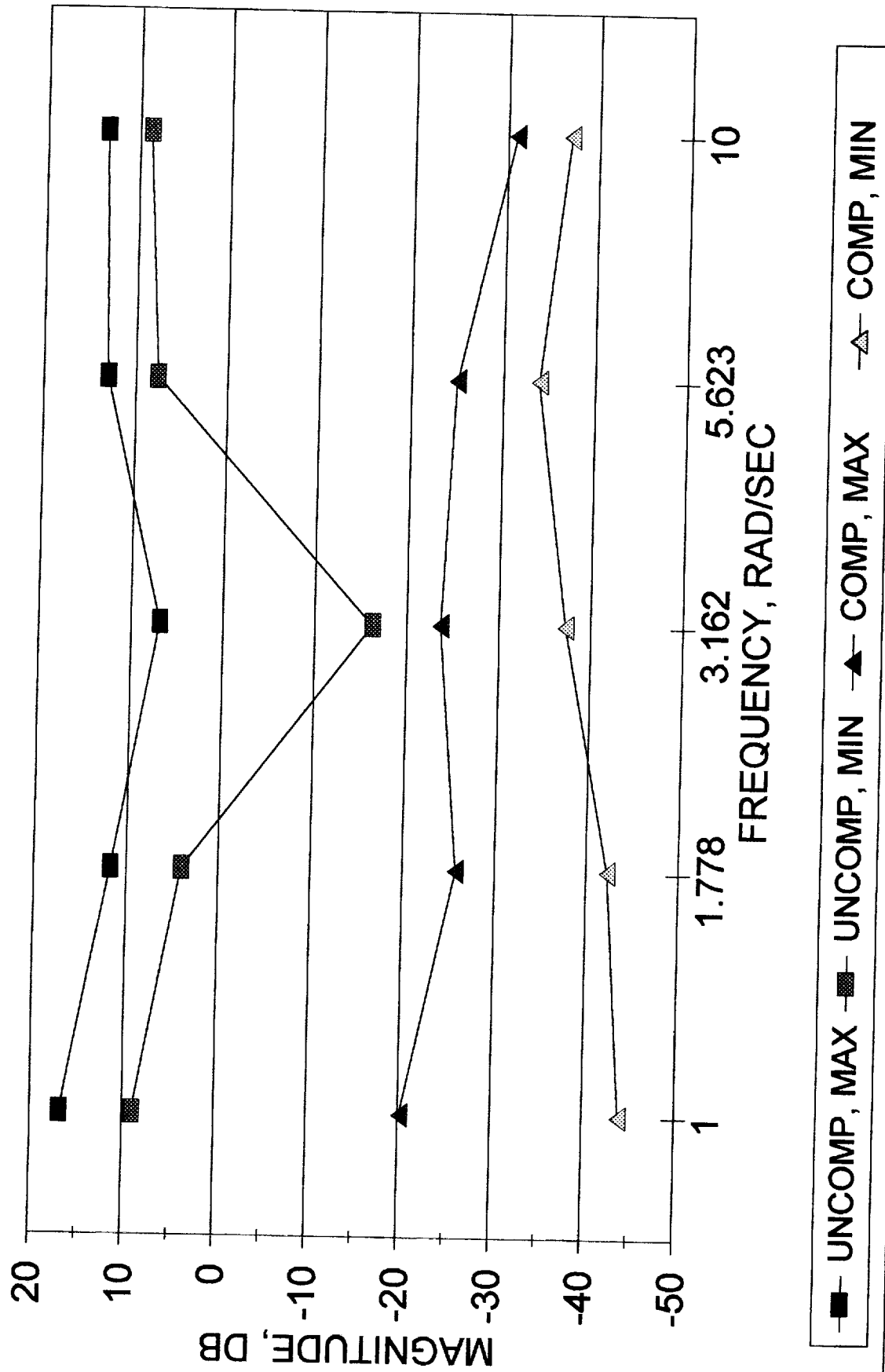
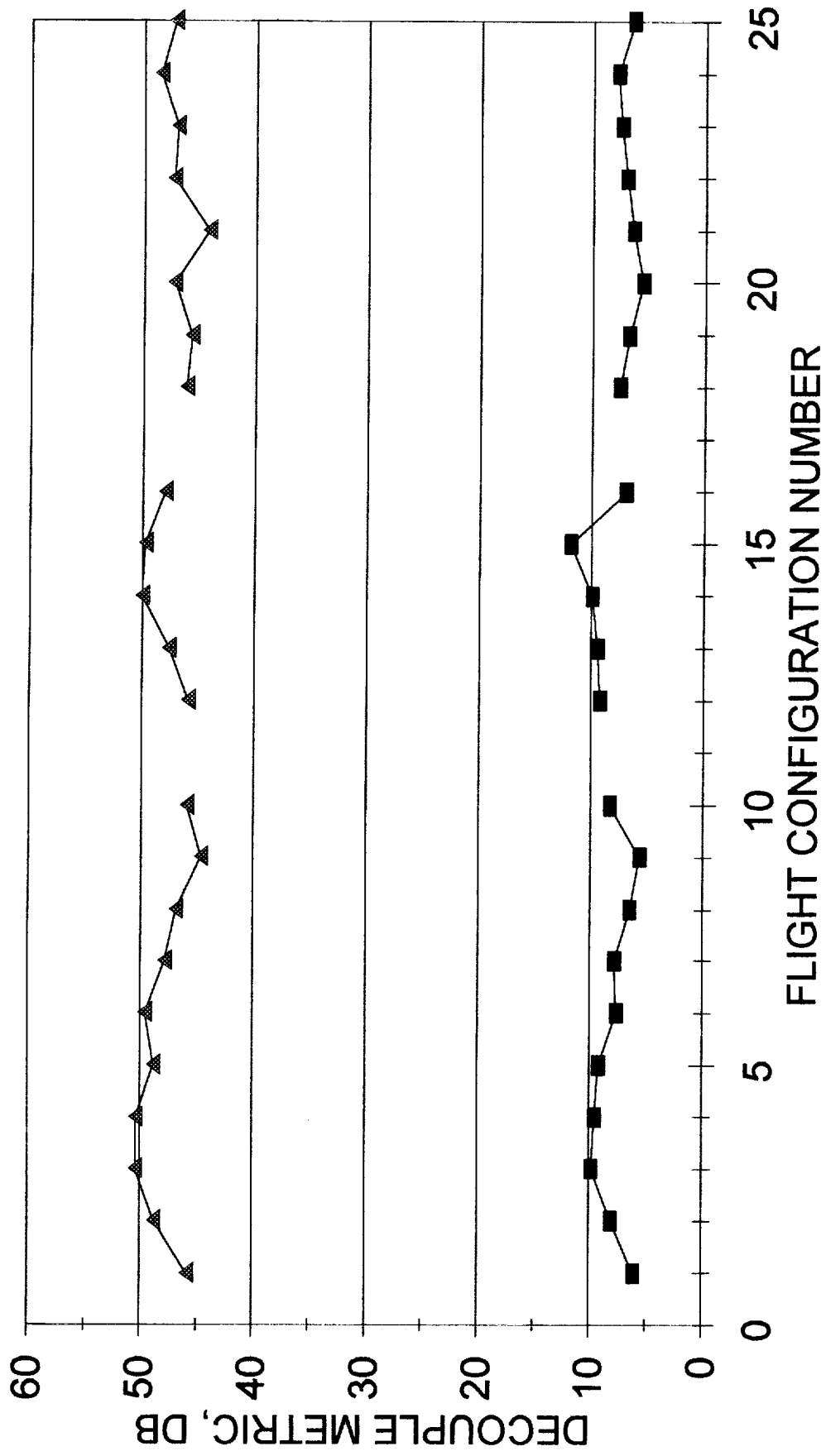


Figure 4.16 **SCATTER PLOT**
ROLL / PITCH



■ UNCOMP METRIC ▲ COMP METRIC

Figure 4.2 **SCATTER PLOT**
HEAVE / PITCH

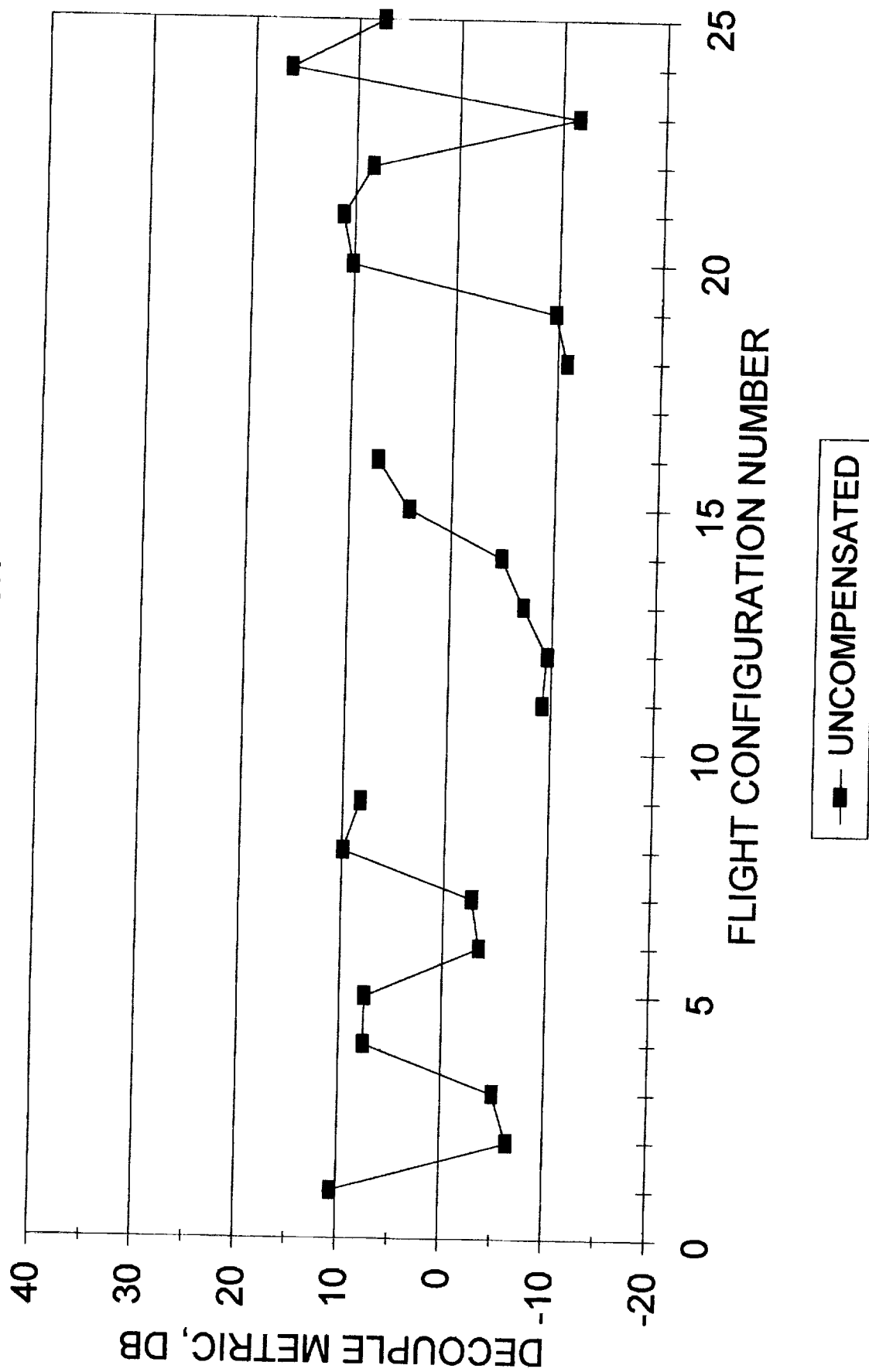


Figure 4.3a **FREQUENCY PLOT**
YAW / PITCH

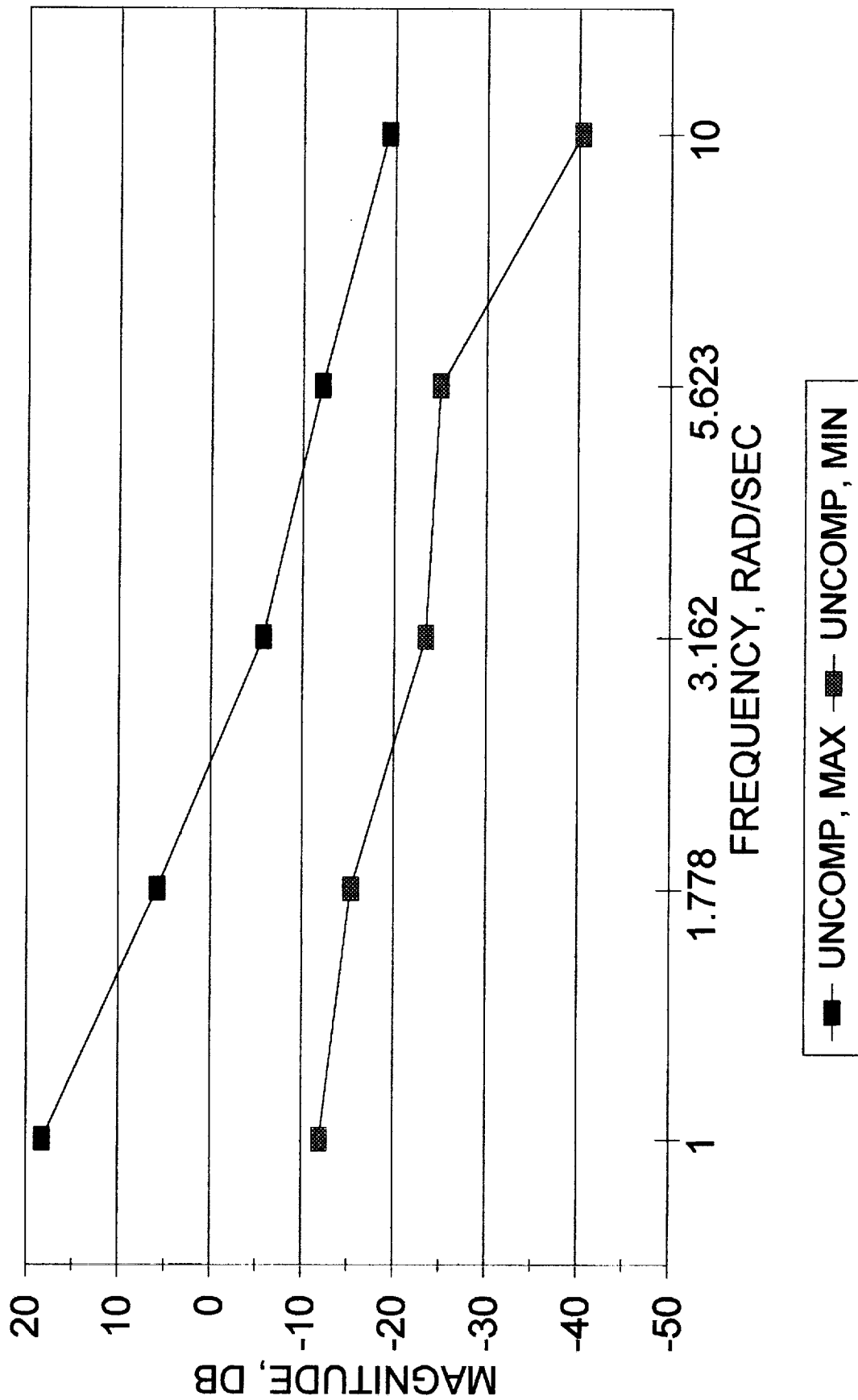


Figure 43_b **SCATTER PLOT**
YAW / PITCH

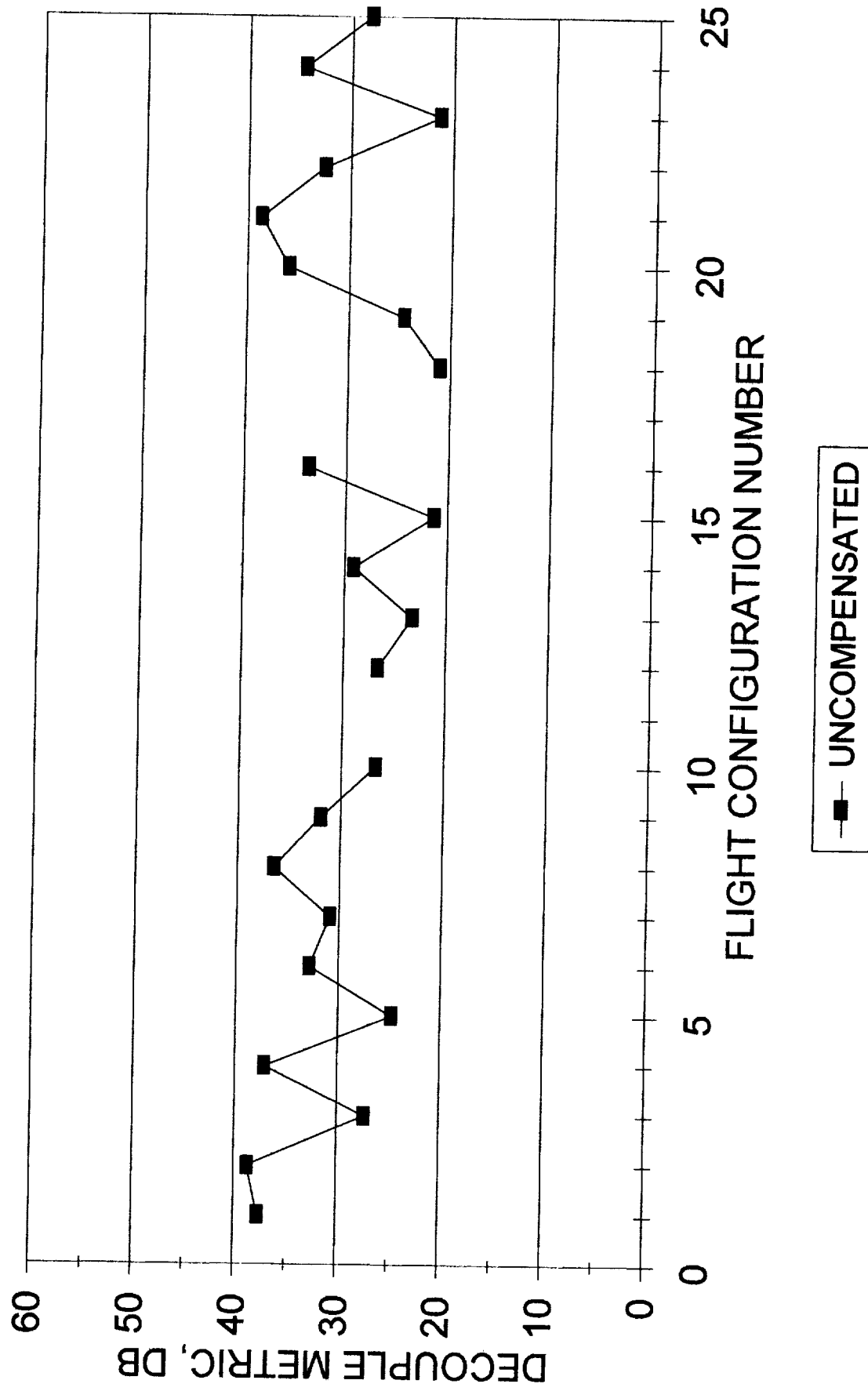


Figure 5 HOVER CONFIGURATION, COLLECTIVE UNIT STEP INPUT

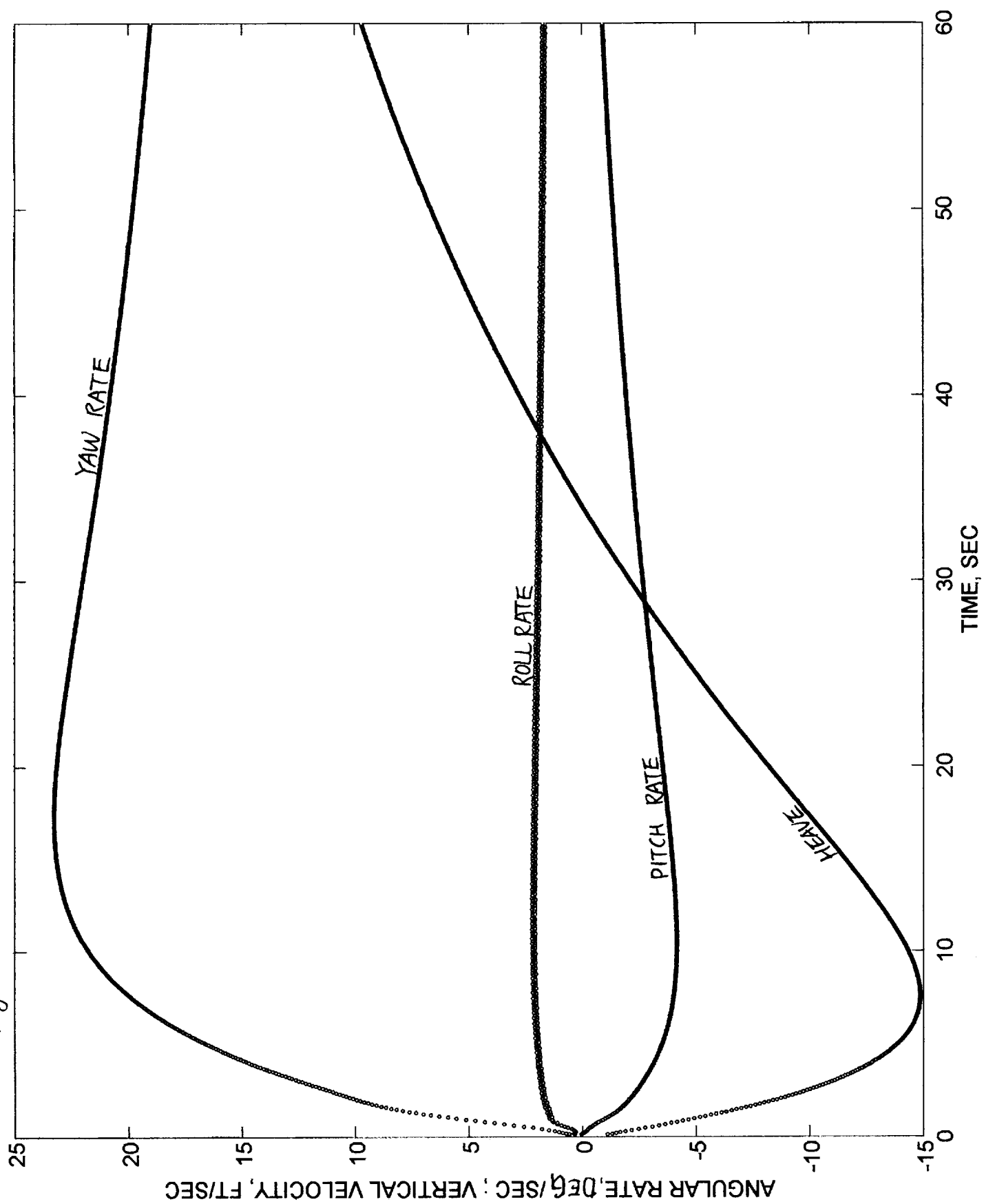


Figure 5.1a **FREQUENCY PLOT**
ROLL / HEAVE

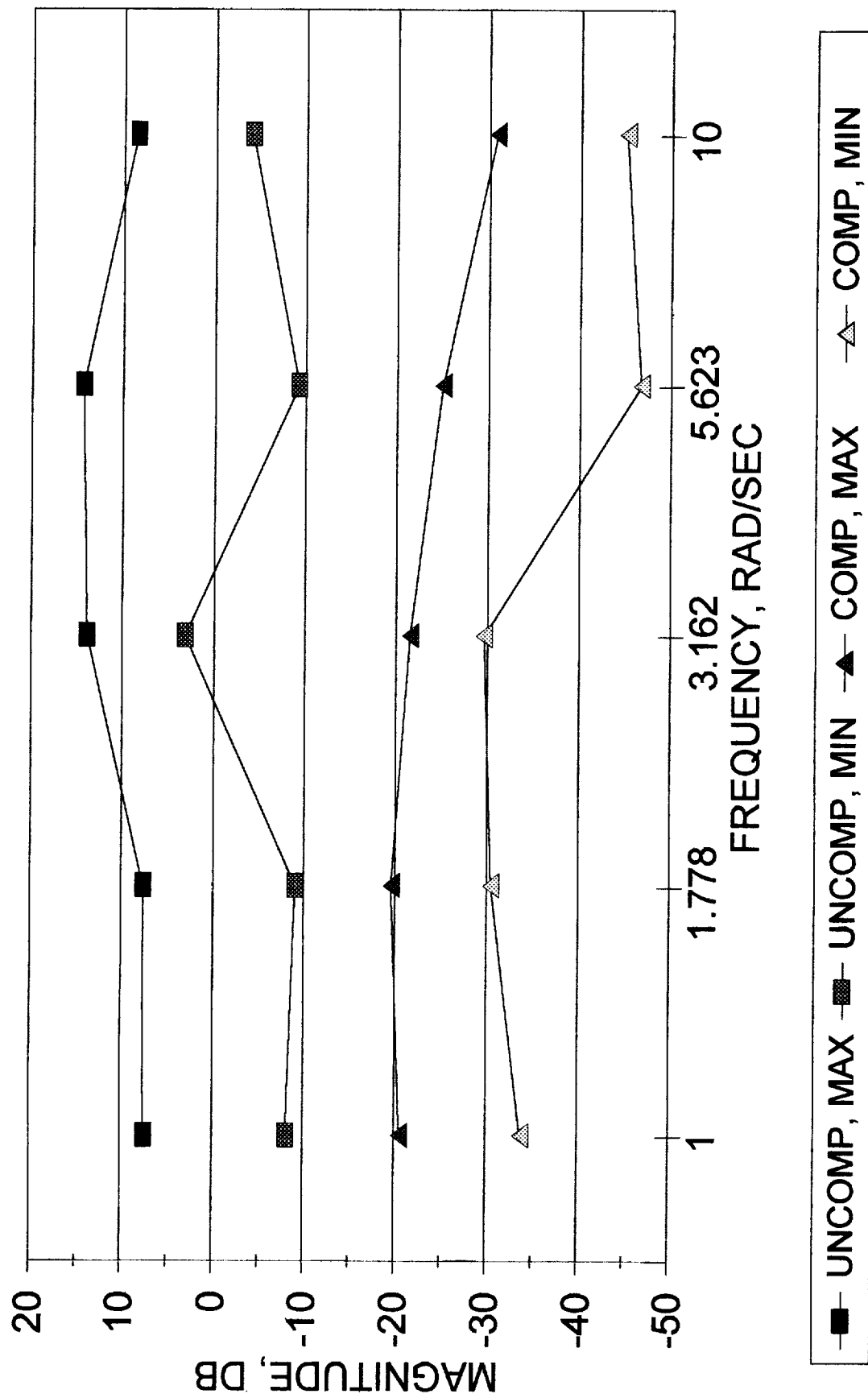
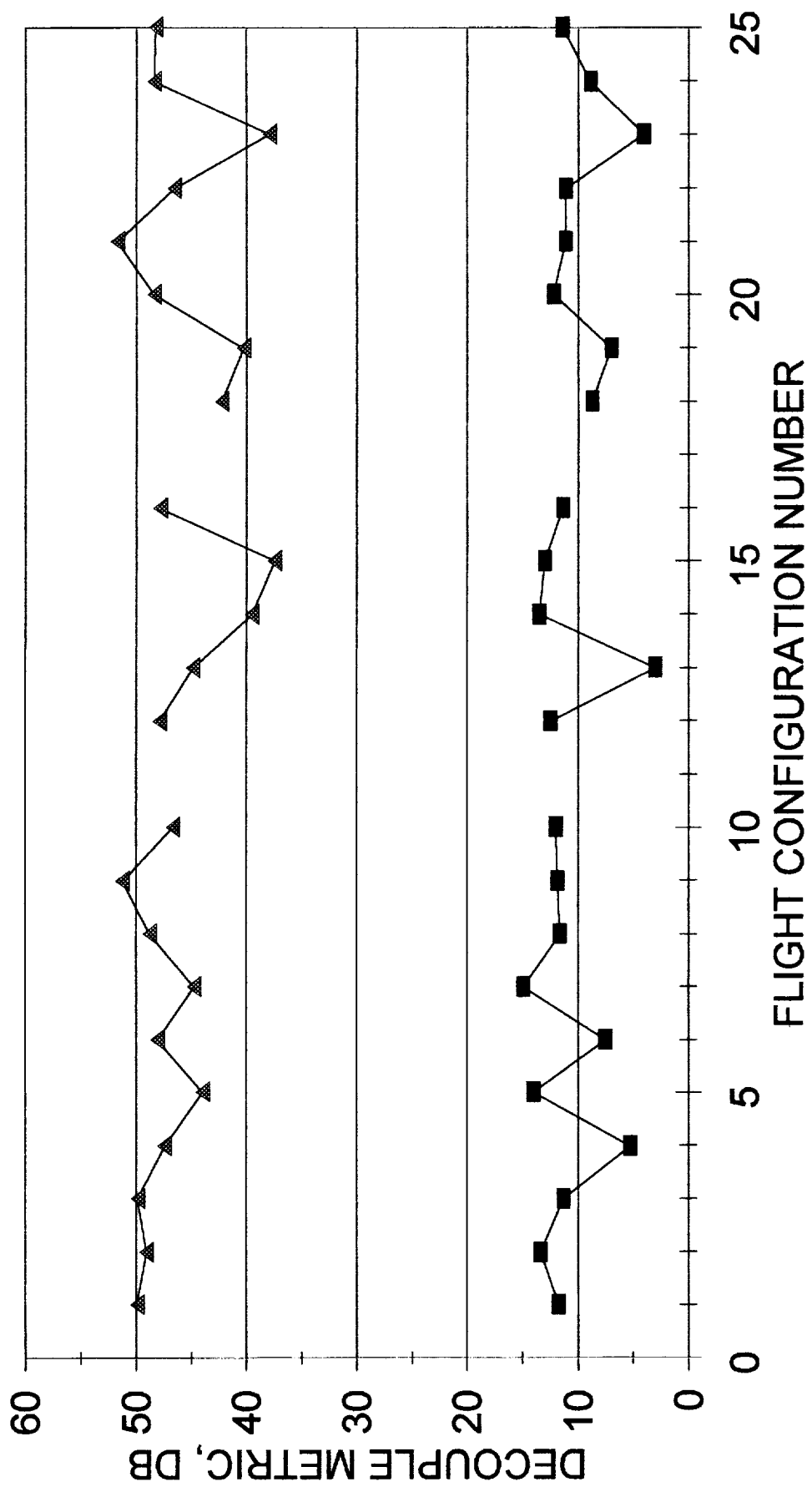


Figure 5.1_b **SCATTER PLOT**
ROLL / HEAVE



■ UNCOMP METRIC ▲ COMP METRIC

Figure 5.2 a **FREQUENCY PLOT**
PITCH / HEAVE

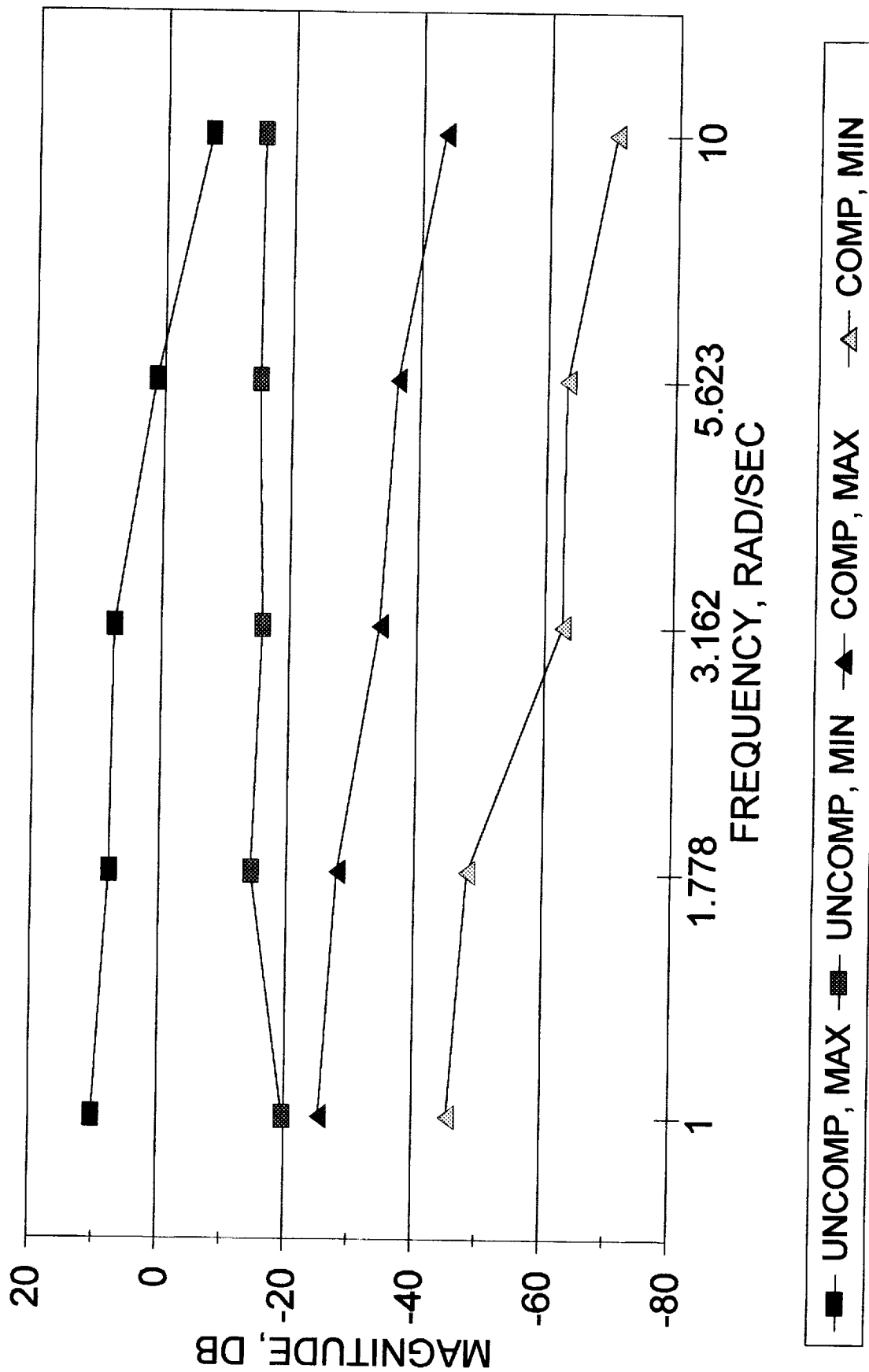


Figure 5.2_b **SCATTER PLOT**
PITCH / HEAVE

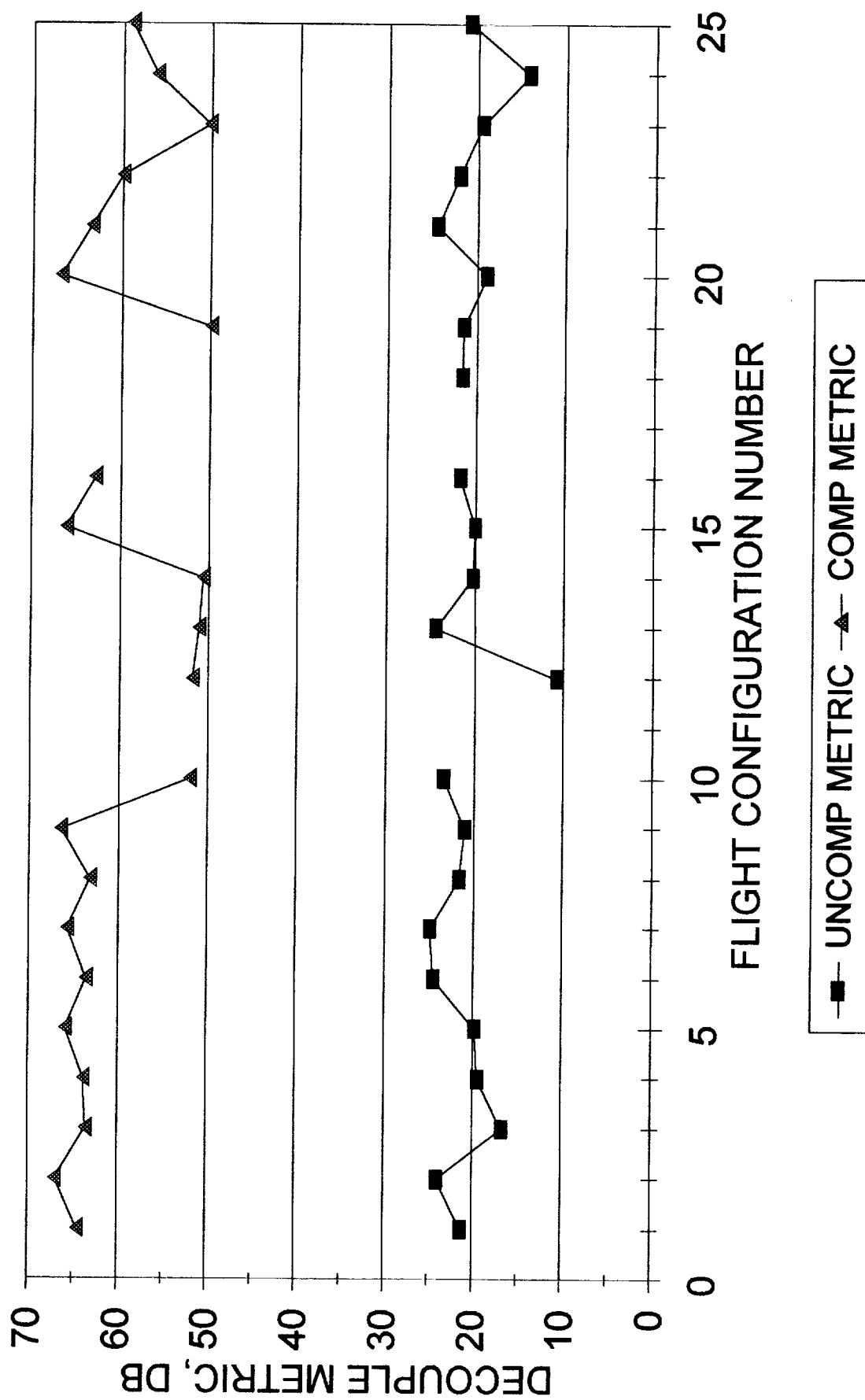


Figure 5.3a **FREQUENCY PLOT**
YAW / HEAVE

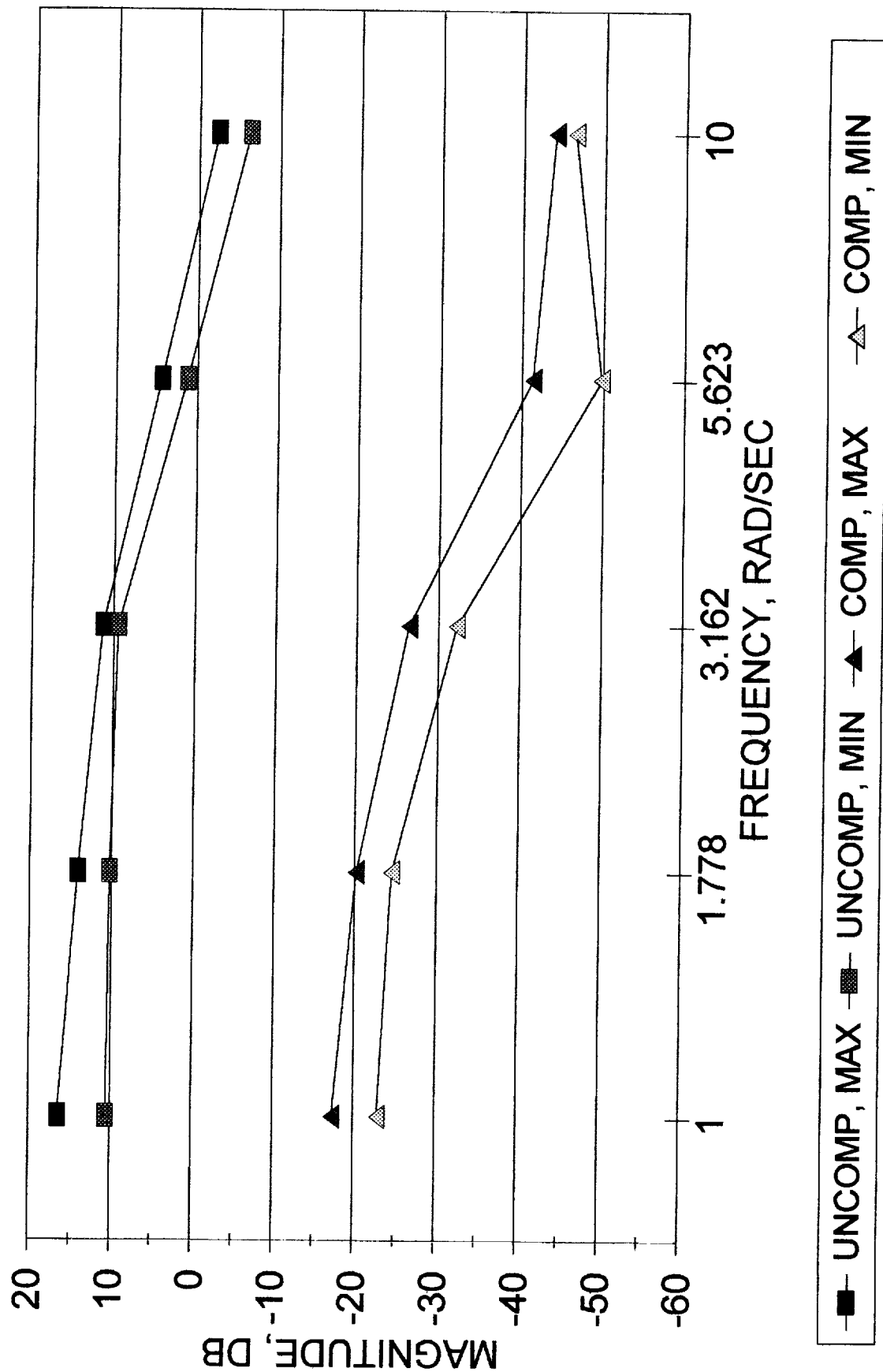
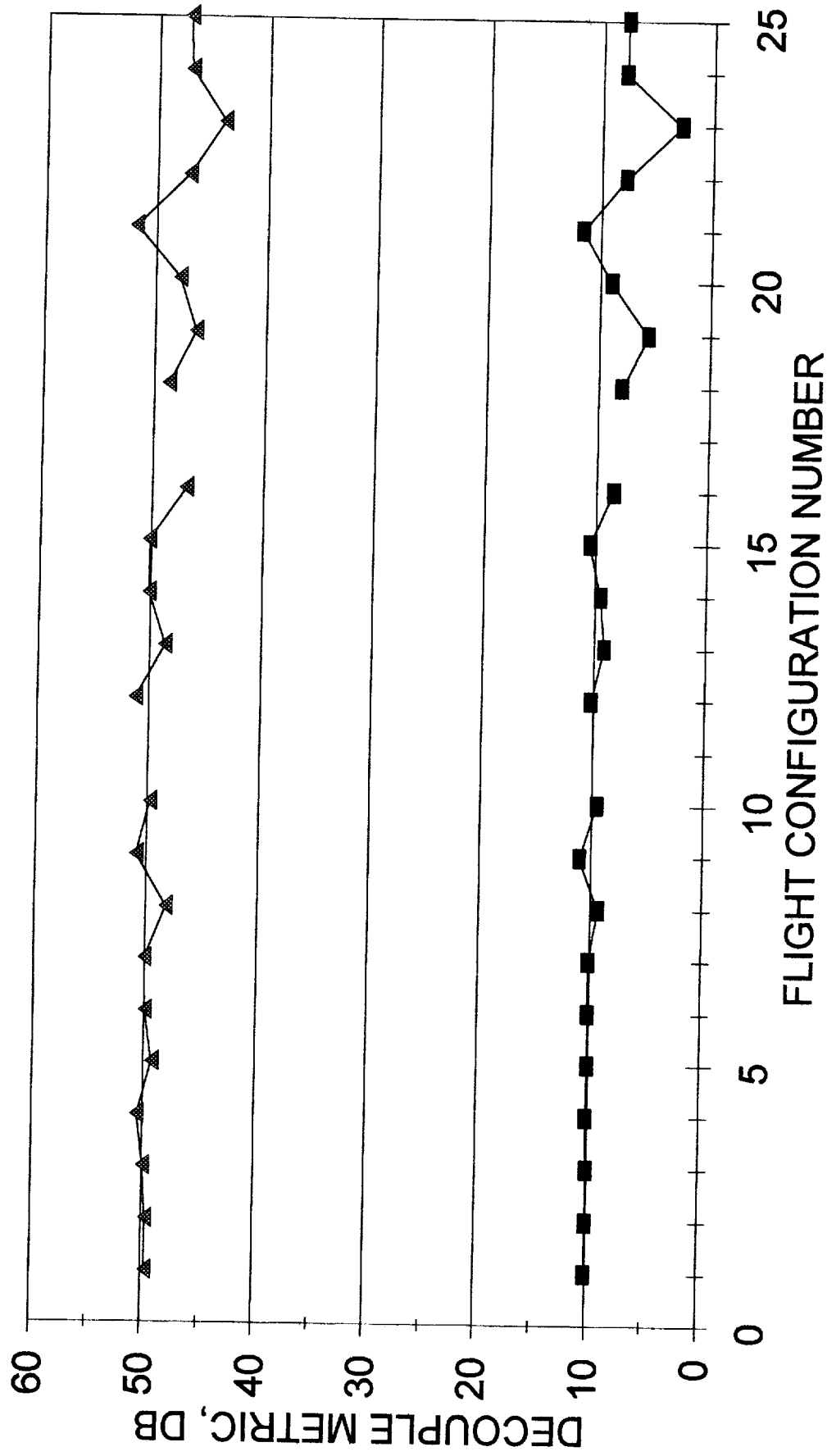


Figure 5.3.6 **SCATTER PLOT**
YAW / HEAVE



■ UNCOMP METRIC ▲ COMP METRIC

Figure 6 HOVER CONFIGURATION, YAW STEP INPUT

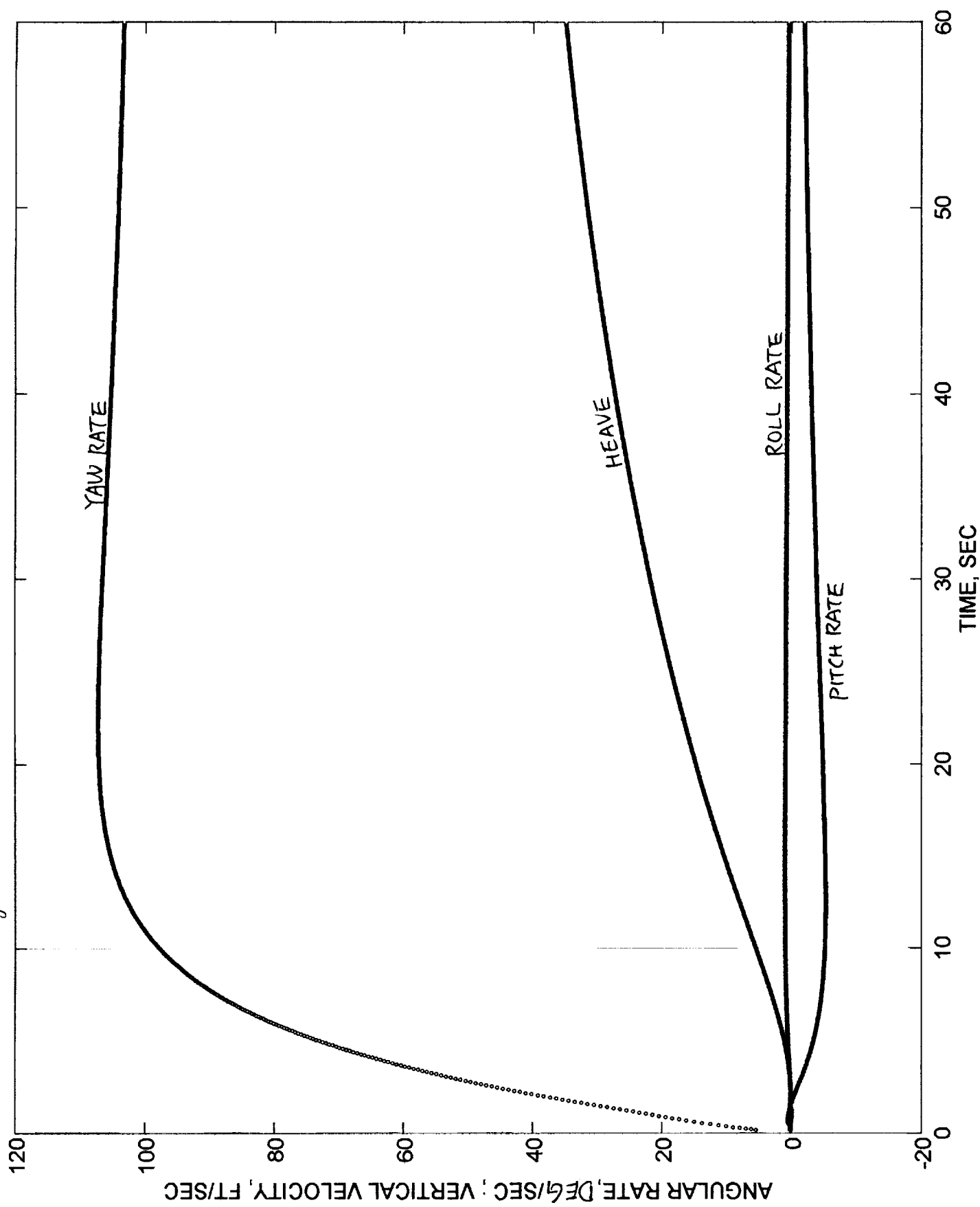


Figure 6.1a **FREQUENCY PLOT**
ROLL / YAW

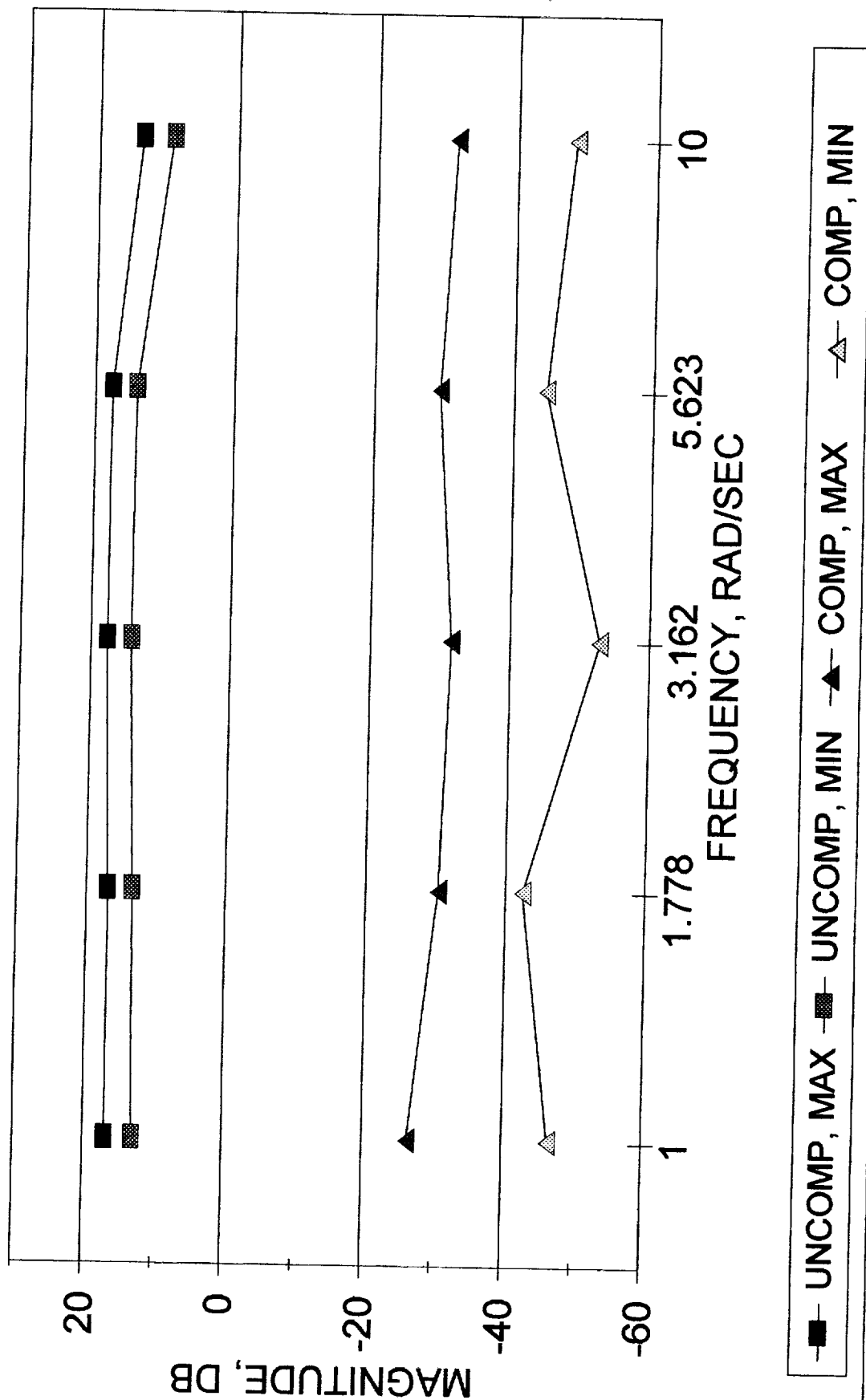


Figure 6.1b **SCATTER PLOT**
ROLL / YAW

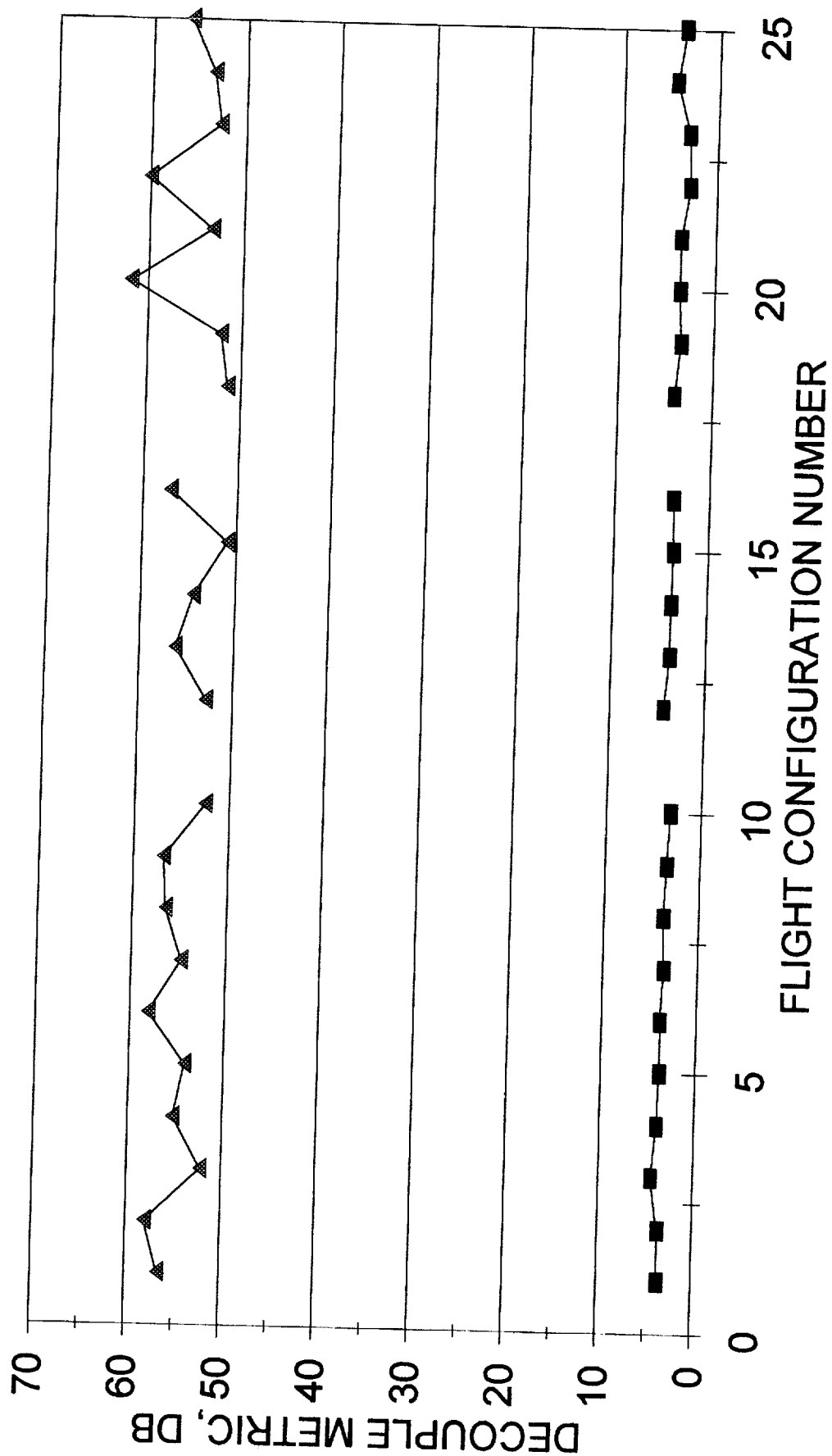
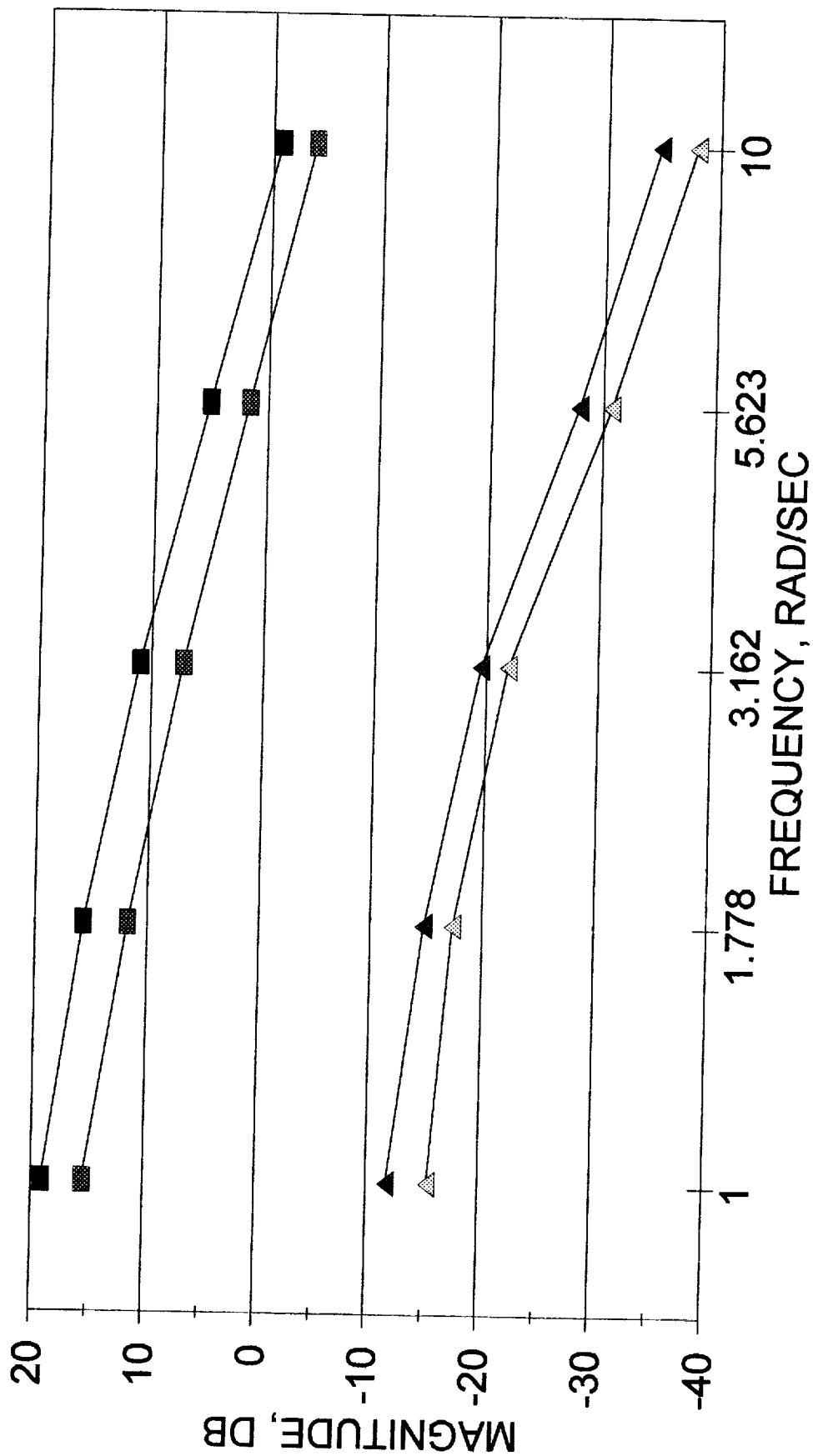


Figure 6.2a

PITCH / YAW



■ UNCOMP, MAX ■ UNCOMP, MIN ▲ COMP, MAX ▲ COMP, MIN

Figure 6.2_b **SCATTER PLOT**
PITCH / YAW

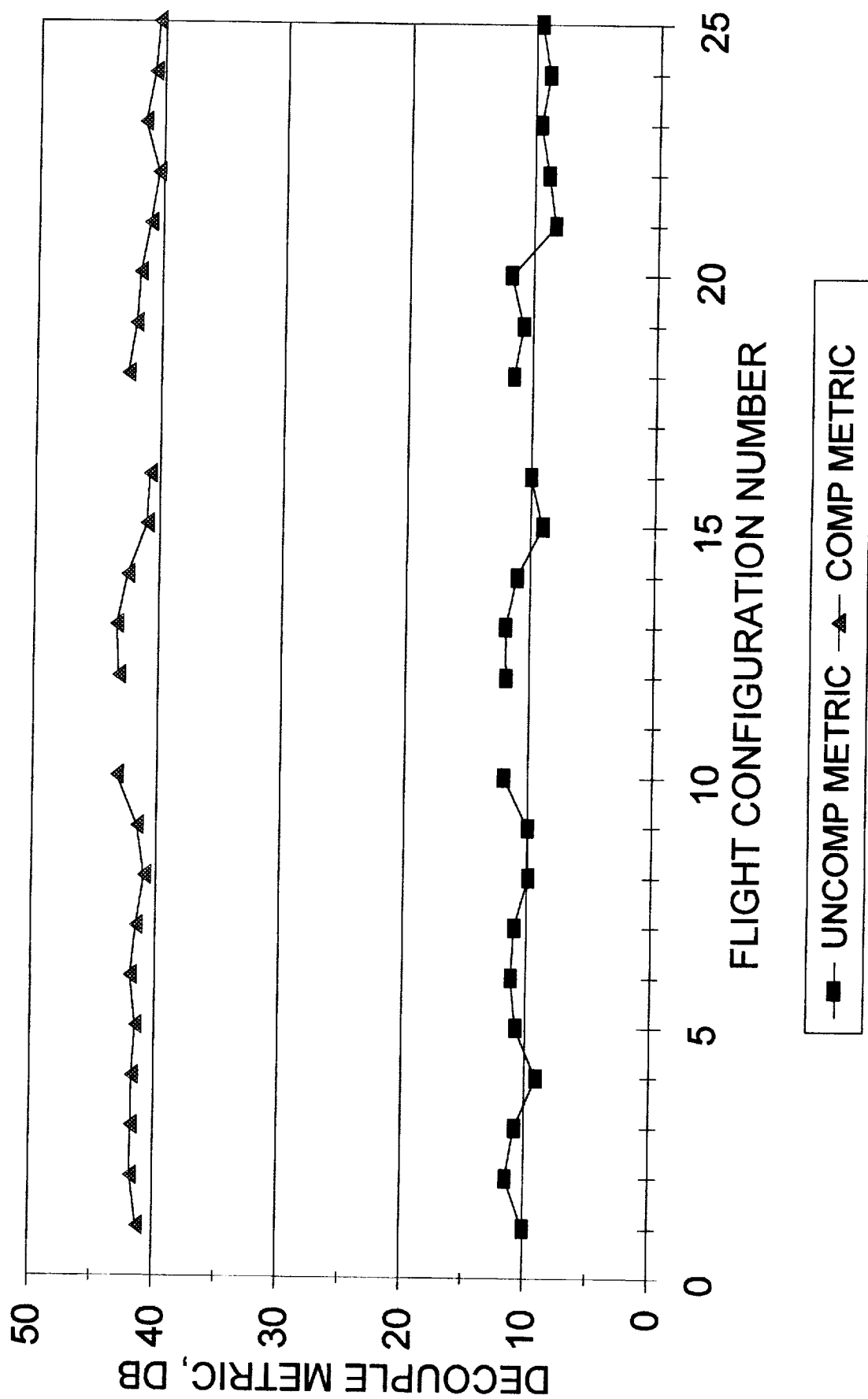


Figure 6.3a **FREQUENCY PLOT**
HEAVE / YAW

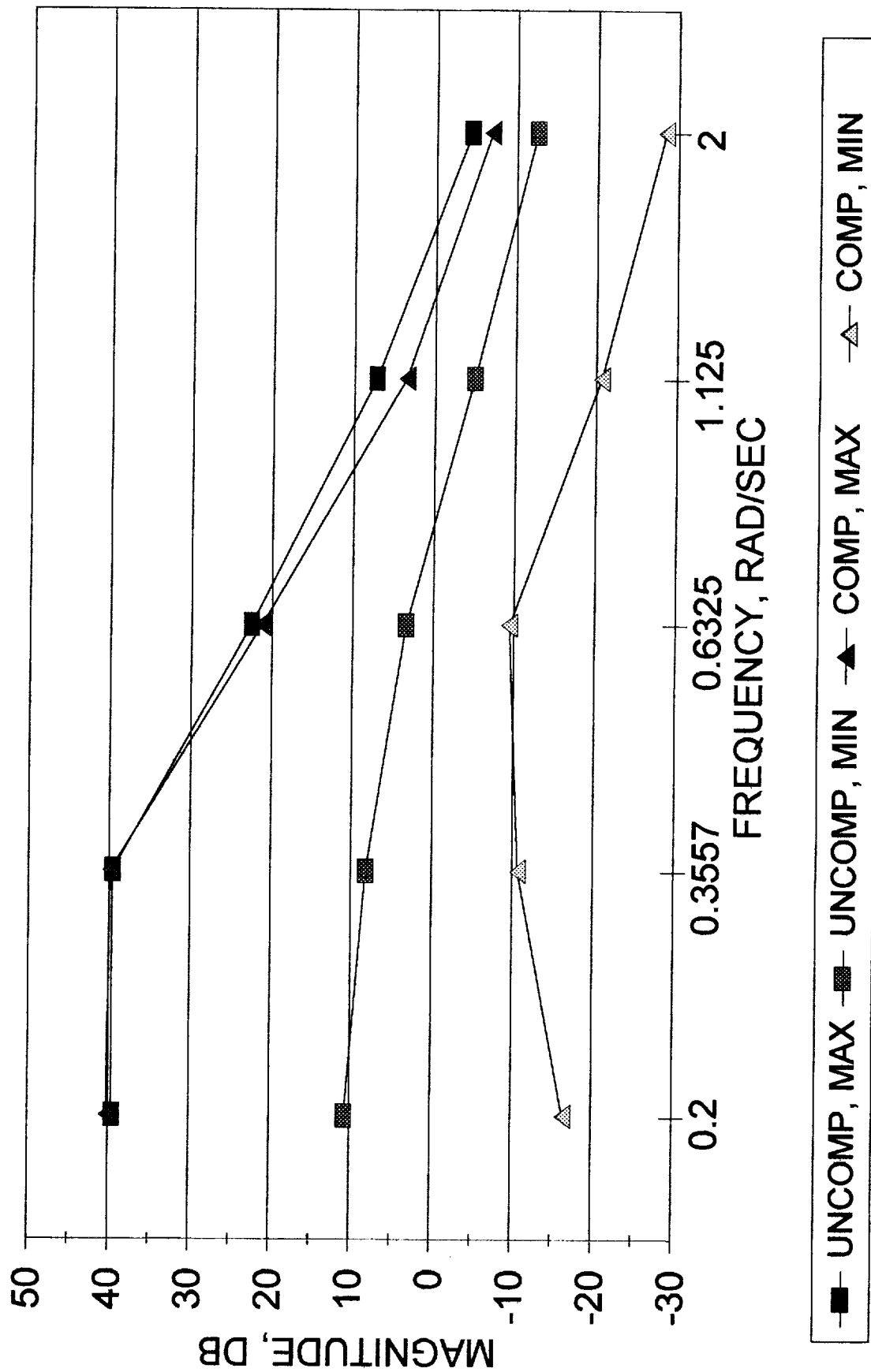
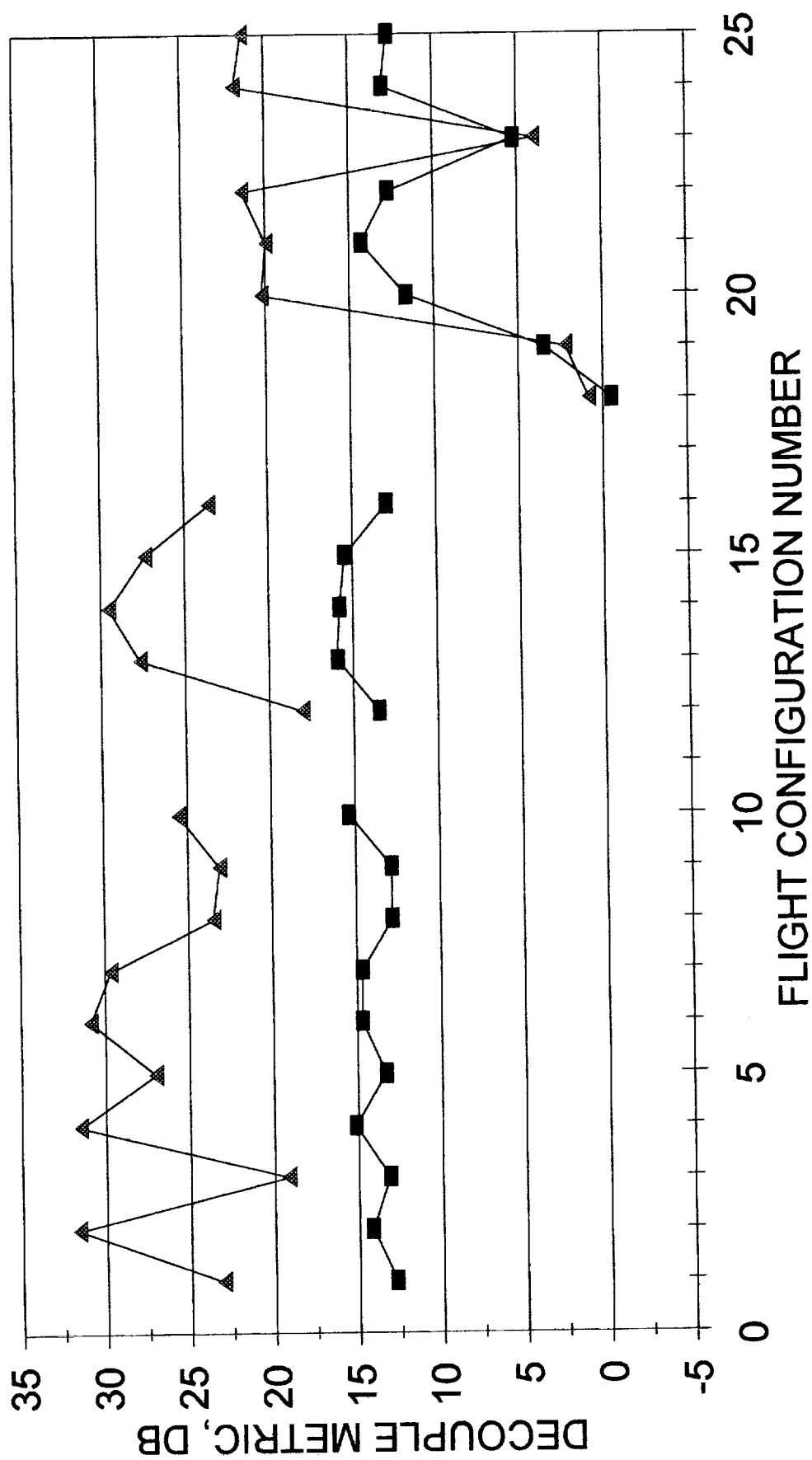


Figure 6.3_b **SCATTER PLOT**
HEAVE / YAW



—■— UNCOMP METRIC —▲— COMP METRIC